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SINGLE-PEAKEDNESS IN WEIGHTED AGGREGATION OF FUZZY OPINIONS IN A FUZZY GROUP

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Abstract: In this paper it is considered a formal approach to the problem of aggregating individual opinions in a fuzzy group, when alternatives can be represented in a real hyper-space and each individual defines his/her fuzzy set of non rejectable alternatives. On one hand, weighted aggregation rule for consensus opinion is axiomatically justified. On the other hand, it is shown a sufficient condition for the atability of such consensus solution.
Keywords: aggregation rules, group decision making, fuzzy opinions.

1. INTRODUCTION

Every society is faced with the problem of opinion aggregation each time its individuals define different judgments or different preference attitudee. Amalgamating them into a consensus represents in this way a key point for the development of any group of persons. However, as shown by Arrow (1951, 1964), there is no general methodology for aggregating crisp individual preferences through a "social welfare function" satisfying some natural rationality conditions. Two ways for avoiding such a result have been proposed in the past: relaxing the concept of solution by considering, for example, "social choice functions" (Sen, 1970), or constraining the preferences domain of individual by assuming, for example, that such crisp preferences verify "single-peakedness" property (Black, 1958). This paper is based on the last approach, but allowing a continuous strength of preferences.

The three seminal books oited above suppose that each

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ndividual i defines a crisp binary preference relation R_i o
e set of feasible alternatives X (xP_iy will denote th
R_iy holds but not yR_ix). Black's single-peakedness mean
at there exists a strict ordering S on X such that al
dividual preference orderings can be represented by
eference curve with only one peak (with one or tw
ements), in such a way that on each side of such a peak i
opes downwards: formally, for each individual i and al
stinct alternatives $x,y,z\in X$ the relation xP_iz hold
enever xR_iy for some alternative y between X and z (xSySz
r zSySx). Then it was shown that the method of majority
ecision leads to a consensory transitive ordering on the set
f alternatives. Inada (1964) has pointed out that
ingle-peakedness with respect to the entire set of
lternatives is not necessary: single-peakedness with respect
o every triple of alternatives is enough.

. FORMAL DESCRIPTION OF THE MODEL

Let $\beta:G\to[0,1]$ be a fixed fuzzy group of individuals
experts), G having two elements at least; $\beta(i)>0$, $\forall i\in G$, i
e degree of competence of individual i (see Cholewa, 1985,
r a discussion of the concept of competence), and let u
ssume that the set of (at least two) feasible alternatives X
n be represented as a convex subset of the real hyper-space
. This does not seem a serious restriction, since most
ractical problems are multidimensional in nature according a
inite number of single characteristics, each one usually
epresented in the real line, but it requires a continuous
egree in such a set of feasible alternatives. Individuals
ill be supposed to give their opinions through a fuzzy
reference, that is, a fuzzy set of non-rejectable
lternatives $\mu_i:X\to[0,1]$, where $\mu_i(x)$ represents the degree of
embership of alternative x in the set of solutions, as given
y individual i. Following Montero (1985), we must be able to
efine an aggregation rule, that is, a correspondence

$$* : (\mathcal{F}(X)\times\mathcal{P}(G)) \times (\mathcal{F}(X)\times\mathcal{P}(G)) \to (\mathcal{F}(X)\times\mathcal{P}(G))$$

hich assigns to each pair of opinions $\mu_A,\mu_B\in\mathcal{F}(X)$ from two
isjoint and non-empty groups $A,B\in\mathcal{P}(G)$ an opinion $\mu_{A\cup B}\in\mathcal{F}(X)$
f the union group $A\cup B\in\mathcal{P}(G)$, satisfying the associativity and
ommutativity:

$$((\mu_A,A)*(\mu_B,B))*(\mu_C,C) = (\mu_A,A)*((\mu_B,B)*(\mu_C,C))$$

$$(\mu_A,A)*(\mu_B,B) = (\mu_B,B)*(\mu_A,A)$$

or arbitrary disjoint and non-empty groups $A,B,C\in\mathcal{P}(G)$.

In this way, opinion μ_A of a group A will be represented
y the pair (μ_A,A) and

$$(\mu_A,A)*(\mu_B,B) = (\mu_{A\cup B},A\cup B) \qquad \forall A,B\neq\emptyset,\ A\cap B=\emptyset$$

It can be assumed that the aggregated opinion $\mu_{A\cup B}$ depends on the members of both groups A and B through their sizes, card(A) and *card*(B), and their associated competence β_A and β_B, obtained by aggregating the individual competences. That is, by applying an associative and commutative correspondence

$$@ : ([0,1]\times\mathcal{P}(G)) \times ([0,1]\times\mathcal{P}(G)) \to ([0,1]\times\mathcal{P}(G))$$

$$(\beta_A,A)@(\beta_A,B) = (\beta_{A\cup B},A\cup B) \qquad \forall A,B\neq\emptyset,\ A\cap B=\emptyset$$

which assigns an aggregated competence $\beta_{A\cup B}\in[0,1]$ of the union group $A\cup B\in\mathcal{P}(G)$ of two disjoint and non-empty groups $A,B\in\mathcal{P}(G)$, and it can be assumed also that $\beta_{A\cup B}$ depends on A and B only through their competence (β_A and β_B, respectively) and their size ((card(A) and card(B), respectively).

Obviously, input data of our aggregation problem must be all the individual opinions $\{\mu_{(i)}=\mu_i\}_{i\in G}$ and their associated individual competences $\{\beta_{\{i\}}=\beta(i)\}_{i\in G}$, and both aggregation rules must be each one ethical and connected in a rational way (as shown in Montero, 1988a, not every opinion aggregation rule * is compatible with any fixed competence aggregation rule @). For example, the following conditions (i), (ii), (iii) and (i'), (ii'), (iii') can be easily accepted for @ and *, respectively:

(i) $\beta_{A\cup B}=\beta_{A'\cup B'}$ holds for any non-empty groups being $A\cap B=A'\cap B'=\emptyset$ and such that

$$card(A)=card(A'),\ \beta_A=\beta_{A'}$$
$$card(B)=card(B'),\ \beta_B=\beta_{B'}$$

(ii) $\beta_{A\cup B}=\beta_B$ holds for any non-empty groups ($A\cap B=\emptyset$) such that $\beta_A=\beta_B$.

(iii) If $\beta_A\geq\beta'_A$ and $\beta_B\geq\beta'_B$ for two non-empty and disjoint groups A and B, then $\beta_{A\cup B}\geq\beta'_{A\cup B}$.

(i') $\mu_{A\cup B}=\mu_{A'\cup B'}$ holds for any non-empty groups being $A\cap B=A'\cap B'=\emptyset$ and such that $\mu_A=\mu_{A'}$ and $\mu_B=\mu_{B'}$ and

$$card(A)=card(A'),\ \beta_A=\beta_{A'}$$
$$card(B)=card(B'),\ \beta_B=\beta_{B'}$$

(ii') $\mu_{A\cup B}(x)=\mu_B(x)$ holds for any non-empty groups ($A\cap B=\emptyset$) such that $\mu_A(x)=\mu_B(x)$.

(iii') If $\mu_A(x)\geq\mu'_A(x)$ and $\mu_B(x)\geq\mu'_B(x)$ hold for two non-empty and disjoint groups A and B, then $\mu_{A\cup B}(x)\geq\mu'_{A\cup B}(x)$.

Under these conditions for both aggregation rules it make

$_A$ is said to be δ-decisive in competence over a group B ($A\cap B=\emptyset$) with competence β_B ($\beta_A\neq\beta_B$) if $\beta_{A\cup B}=\delta.\beta_A+(1-\delta).\beta_B$; a roup A with opinion μ_A is said to be δ-decisive in opinion ver a group B ($A\cap B=\emptyset$) with opinion μ_B and relative to a ixed alternative $x\in X$ ($\mu_A(x)\neq\mu_B(x)$) if

$$\mu_{A\cup B}(x)=\delta.\mu_A(x)+(1-\delta).\mu_B(x)$$

. ETHICAL PROPERTIES OF THE WEIGHTED MEAN RULE

The following result has been proved in Montero (1988a), nd it can be considered as an axiomatic justification for he weighted mean rules.

heorem 1. Let us consider opinion aggregation rules $*$ erifying conditions (i'), (ii') and (iii'). Then, the inimum ratio opinion decisiveness $\delta/\beta(i)$ of individuals eads to the maximum for the weighted opinion aggregation ule such that

$$_{A\cup B}(x)=(card(A).\beta_A.\mu_A(x)+card(B).\beta_B.\mu_B(x))/(card(A\cup B).\beta_{A\cup B})$$

or any non-empty and disjoint groups $A,B\in G$, β being the ggregated weighted competence given by

$$\beta_{A\cup B}=(card(A).\beta_A+card(B).\beta_B)/card(A\cup B)$$

or any non-empty and disjoint groups $A,B\in G$. Moreover, this ompetence aggregation rule @ maximizes the minimum ratio ompetence decisiveness $\delta/\beta(i)$ of individuals, and it erifies conditions (i), (ii) and (iii).

It must be pointed out that the concept of an aggregation ule considered here generalizes an analogous aggregation peration of Fung and Fu (1975), avoiding a restrictive esult obtained by them (and thus we can see that the main ause of such restrictive result is just that their ggregation rule does not depend on the size of the ggregated groups). Other axioms will lead to different ggregation rules, including those "mixed" rules of Fung and u (see Montero, 1988b, for an analysis in the context of ulticriteria aggregation, and Dubois and Prade, 1985, for a elation with various fuzzy set aggregation connectives).

In any case, the weighted aggregation rule of Theorem 1 erifies ethical conditions translated into this context from lassical impossibility theorems: the universal domain has een assumed by definition, the anonymity will be assured due o condition (i'), the unanimity will be assured by condition ii'), the non-negative response and independence of rrelevant alternatives will hold due to condition (iii') and ven the neutrality holds. Some formal definitions of all hese ethical conditions are written below. Alternative efinitions can be found in the literature (see, e.g., Dubois nd Koning, 1989).

nonymity: Let us consider A,A',B,B'$\in\mathcal{P}(G)$ being non-empty

groups such that $A\cap B=A'\cap B'=\emptyset$, with $\beta(A)=\beta(A')$, $\beta(B)=\beta(B')$ and $card(A)=card(A')$, $card(B)=card(B')$. If $\mu_A=\mu_{A'}$ and $\mu_B=\mu_{B'}$ hold, then

$$(\mu_A,A)*(\mu_B,B)=(\mu_{A\cup B},A\cup B)$$
$$(\mu_{A'},A')*(\mu_{B'},B')=(\mu_{A'\cup B'},A'\cup B')$$

must verify that $\mu_{A\cup B}=\mu_{A'\cup B'}$.

Independence of Irrelevant Alternatives: Let $A,B\in\mathcal{P}(G)$ be disjoint and non-empty groups and let us suppose that

$$\mu_A(x)=\mu'_A(x)\ \ \forall x\in Y\subset X,\ \mu_B(x)=\mu'_B(x)\ \ \forall x\in Y\subset X$$

Then

$$(\mu_A,A)*(\mu_B,B)=(\mu_{A\cup B},A\cup B)$$
$$(\mu'_A,A)*(\mu'_B,B)=(\mu'_{A\cup B},A\cup B)$$

must verify that

$$\mu_{A\cup B}(x)=\mu'_{A\cup B}(x)\qquad \forall x\in Y\subset X$$

Neutrality: Let $A,B\in\mathcal{P}(G)$ be disjoint and non-empty groups, and $P:X\to X$ be an arbitrary one-to-one mapping. If for each opinion $\mu\in\mathcal{F}(X)$ we define μ^P such that

$$\mu^P(x)=\mu(P(x))\qquad \forall x\in X$$

then

$$(\mu^P_A,A)*(\mu^P_B,B)=(\mu^P_{A\cup B},A\cup B)$$

Non-Negative Response: If $A,B\in\mathcal{P}(G)$ are disjoint and non-empty groups and

$$\mu_A(x)\geq\mu'_A(x)\ \ \forall x\in X,\ \mu_B(x)\geq\mu'_B(x)\ \ \forall x\in X$$

with at least one strict inequality, then

$$(\mu_A,A)*(\mu_B,B)=(\mu_{A\cup B},A\cup B),\ \ (\mu'_A,A)*(\mu'_B,B)=(\mu'_{A\cup B},A\cup B)$$

ought to verify

$$\mu_{A\cup B}(x)\geq\mu'_{A\cup B}(x)\qquad \forall x\in X$$

Unanimity: Let $A,B\in\mathcal{P}(G)$ be disjoint and non-empty groups with identical fuzzy preferences $\mu_A=\mu_B=\mu\in\mathcal{F}(X)$. Then

$$(\mu_A,A)*(\mu_B,B)=(\mu,A\cup B)$$

Analogous ethical conditions (depending only on the size of the aggregated groups, as shown in Montero, 1985) could be imposed to competence aggregation operations @, and it is easy to see that they are satisfied by weighted competence aggregation of Theorem 1.

Finally, we must point out a clear criticism to this approach, since it is assumed that the assignments are commensurable, and furthermore, if $\mu_i(x)>\mu_j(x)$ it is understood that individual i prefers alternative x more than individual j does. The problem of interpersonally comparing preference intensities is, as pointed out by Pattanaik (1971), part of the broader and controversial problem of the possibility of knowing other minds; but though in the present

sentation on the real hyper-space of the set of
natives is obviously ot necessarily unique. Hence, if
real representations in a convex subset X of $\mathbb{R}^r$ exist,
ust look for one of them where all the individual
ons are concave. And it has been pointed out that the
ence of such concave-compatible representation is not
ed for arbitrary profiles of individual fuzzy
rences (trivial examples can be given by considering
e-peaked intensity preferences with constant intensities
treme alternatives).
reover, in practice only a finite number of alternatives
be evaluated at the first step. Some reasonable real
sentations could then be considered in order to
ntially search for better alternatives: for example, if
natives are evaluated according to two characteristics,
one represented by a real number between 0 and 10, the
idual intensities could be initially estimated only for
lternatives ((2.j,2.k)/j,k=0,1,...,5), that is, for 36
natives covering as a net the whole space of
natives [0,10]x[0,10]; if concavity holds for this real
sentation of individual preferences, then a best
native must be looked for around the peaks obtained by
weighted mean aggregation; for example, if only one
um is reached in alternative (4,6), it will be enough to
ler in the next step only the subspace of alternatives
x[5,7], where another net of points could be established
der to repeat the procedure. If concavity does not hold,
ps a concave representation could be tried by
dering appropriate order preserving one-to-one mappings
the initial evaluation space [0,10] of each
cteristic into different real intervals, or perhaps by
dering a deeper transformation (alternatives could be
ibed in terms of different but more appropriate
cteristics).

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:thod of measuring and interpersonally comparing th
itensities of individual preferences, it can hardly be
:nied that ethically it is desirable to take them into
:count. An intereeting attempt in this eense is that of
nsnick (1986).

- CONCAVITY OF INDIVIDUAL PROFILES

In our context, single-peakedness means that alternatives
e ordered in the real hyper-space R^k of k characteristics
such a way that, as we go from left to the right in each
aracteristic, every individual preferences increases up to
peak , and then decreases after we pass it. As shown in
ntero (1989), such a property will hold when the considered
tensity is concave from an analytic point of view:
finition 1. Let $\mu:X\to[0,1]$ be a fuzzy set of feasible
ternatives defined over a convex subset of the real
per-space $X\subset R^k$. Then μ is said to be "concave" if

$$\mu(\lambda.x+(1-\lambda).y) \geq \lambda.\mu(x)+(1-\lambda).\mu(y) \quad \forall x,y\in X,\ \forall\lambda\in[0,1]$$

It is clear that a single-peaked representation on the
al line is in its spirit close to Black's single-peakedness
d even to Inada's single-caveness (Inada, 1964), a
ndition less restrictive than single-peakedness which
lows for indifference plateaus, and also assuring a
nsensory transitive solution under the crisp majority rule.
ough it is clear that single-peaked intensity and
ngle-caved intensity are not always concave, the
troduction of concavity is justified due to some
teresting properties which will appear when individual
tensities are concave compatible in our context.
finition 2. A profile of individual intensities
$_i:X\to[0,1]\}_{i\in G}$ defined over a convex set $X\subset R^k$ of
ternatives verifies the property of "concavity" if they are
l concave.

In this way, if concavity is assumed, an important but
sirable restriction on the family of admissible preference
tterns has been introduced, since each individual
eference must be inside the set $\mathcal{C}(X)\subset\mathcal{F}(X)$ of concave
inions. Therefore, if it considered that the restrictions
individual preferences must be just the restrictions on
cial preferences, our aggregation rule * must be defined as
associative and commutative correspondence

$$* : (\mathcal{C}(X)x\mathcal{P}(G)) \times (\mathcal{C}(X)x\mathcal{P}(G)) \to (\mathcal{C}(X)x\mathcal{P}(G))$$

rifying the above ethical conditions.

It must be pointed out that single-peakedness of
dividual intensities does not assure a social single-peaked
inion under the weighted mean rule. Such a closure theorem
n be assured under concavity (its mathematical proof is
ivial).
eorem 2. Let us assume that the concavity property holds,
d let us consider the weighted aggregation rule as given in

disjoint and non-empty groups $A,B\in\mathcal{P}(G)$.

Concavity of a social preference pattern can be understood as a condition which assures an equilibrium and stability in group decision making: a best alternative is around one point, and a manipulation or measurement errors (if they are not too big) can modify in fact the solution, but new solution will not be in any case too far from the initial solution.

The concave individual intensities mean in fact that people are inclined to reach consensus. The single-peakednes of individual intensities seems to be a natural assumption when dealing with single characteristic problems, but if they are non-concave, they represent very clear individual preferences, with people rejecting other alternatives different than their own best alternatives:binary intensities (those verifying $\mu(x)\in\{0,1\}$ $\forall x\in X$) will never be concave unless they are constant (that is, $\mu(x)=\mu(y)$ $\forall x,y\in X$). For example, if there is an individual $i\in G$ such that $\mu(x_i)=1$ but $\mu(y)=0$, $\forall y\neq x_i$, for a fixed alternative $x_i\in X$, our common sense tells us that a satisfactory consensory solution will be very difficult due to such a crisp (absolutely clear) opinion, and in fact there is no representation making such a preference concave. In some way we can conclude that Theorem 2 reveals how "spreaded" intensities (in the sense of concavity) can easily be aggregated according to the weighted mean rule, and points out the expected difficulties in aggregating crisp (or too clear) opinions.

In any case, it also must be pointed out that concavity requires a sensitivity of the decision makers, since around best alternatives the intensity must be strictly decreasing (there is no identical intensities at each side of the peak).

A dual result can be obtained when the values of our intensity preferences μ are understood as degrees of rejecting each alternative by the individuals (like a fuzzy veto instead of a fuzzy preference). It shows the difficulties in aggregating vetos of an arbitrary shape, and its mathematical proof is also trivial.

Theorem 3. Let us consider the weighted aggregation rule * as given in Theorem 1, and let us suppose that each individual opinion verifies convexity, that is,

$$\mu(\lambda.x+(1-\lambda).y)\leq\lambda.\mu(x)+(1-\lambda).\mu(y) \quad \forall x,y\in X,\ \forall\lambda\in[0,1]$$

Then, an aggregated opinion for any pair of disjoint and non-empty groups in G also verifies convexity.

Under the concavity condition, the weighted aggregation will be between moderate alternatives (that is, non-extreme alternatives). Such a property seems in principle desirable for the stability of any social system.

5.- FINAL COMMENTS

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